Effects of growth rate on lateral compositional modulation of InGaAsP/InP(001) grown by metalorganic molecular beam epitaxy

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1. Introduction

InGaAsP quaternary alloy grown on InP (001) substrates is a key material for laser diodes emitting at 1.3 or 1.55 µm wavelength for optical telecommunication systems. However, this alloy system has a miscibility gap over a wide range of the composition, resulting in lateral compositional modulation (LCM) structure [1]. Such a LCM structure leads to degradation of both the carrier mobility [2] and luminescence properties of epitaxial layers [3]. In this report, we describe the effects of the growth rate on the LCM of InGaAsP alloy.

2. Experiments

Several InGaAsP (λ=1.5µm) epitaxial layers, with strain ranging from –0.5% (tension) to +0.3% (compression), were grown on InP (001) substrates using metalorganic molecular beam epitaxy (MOMBE) at growth rates of 0.25 and 0.46 nm/s, respectively. For all samples the InGaAsP layer thickness was 400 nm and the growth temperature was 520˚C. The epitaxial layers were characterized by double crystal x-ray diffraction (DCXRD), cross-sectional transmission electron microscopy (TEM), and photoluminescence (PL) measurement.

3. Results and Discussion

First, we characterized the LCM structure of the InGaAsP layers by DCXRD using asymmetric (224) reflection because the very shallow exit angle makes this geometry very sensitive to lateral non-uniformity [4]. Figure 1(a) shows a series of (224) rocking curves for various InGaAsP layers grown at 0.25 nm/s. In contrast to a compressive strained layer having no additional peaks, tensile strained layers clearly exhibit the side lobes arising from the LCM on both sides of the InGaAsP peaks. The angular separation between the side lobe and the InGaAsP peak corresponds to a modulation wavelength ~100 nm. The side lobe intensity increases with increasing tensile strain, since the amplitude of composition modulation is larger for tensile layers grown deeper within the miscibility gap. The same behavior was observed in the set of samples grown at 0.46 nm/s. However, side lobe intensities for 0.46 nm/s samples are lower than those of 0.25 nm/s ones in the entire strain range as shown in Fig. 1(b). This indicates that the LCM is reduced by increasing the growth rate. Further evidence of this is provided by TEM and PL.

Figure 2 compares [1 $\bar{1}$0] cross-sectional TEM images from two tensile strained InGaAsP layers (ε = –0.37%) grown at different growth rates. The (220) bright-field micrographs depicted in Fig. 2(a) and (b) show two types of contrast modulations arising from the LCM [1]. Fine contrast modulation (~10-nm wavelength) is clearly observed in both micrographs. But a coarse contrast modulation (~100-nm wavelength), related to the x-ray side lobe, is fairly clear for the growth rate of 0.25 nm/s, whereas it is just barely discernible for 0.46 nm/s, as shown in the line profiles of contrast modulation in a direction parallel to surface depicted in Fig. 2(c) and (d). This indicates that the composition modulation with wavelength ~100 nm is reduced by increasing the growth rate.

Fig. 3(a) shows the typical temperature dependence of PL spectra for the LCM structure (–0.25% tensile strained InGaAsP layer grown at 0.25 nm/s). Two distinct PL peaks are observed at around 180 K. Such a peak separation, indicating the LCM [3], also appeared in the spectra of other tensile layers, and the peak separation ΔE increases with increasing tensile strain as shown in Fig. 3(b). The ΔE for 0.46 nm/s samples is lower than that for 0.25 nm/s ones in the entire strain range. This result is consistent with the x-ray result.

4. Conclusions

DCXRD, TEM and PL characterization reveals that increasing the growth rate reduces the LCM of InGaAsP layers grown by MOMBE.

References

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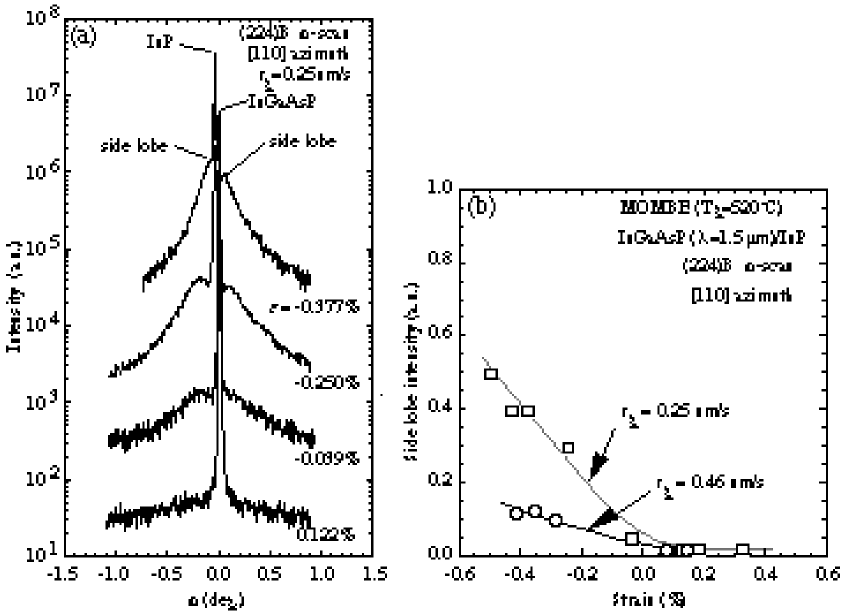

Fig. 1. (224) rocking curves measured by ω-scan for various InGaAsP layers grown at 0.25nm/s (a), and effect of strain and growth rate on side lobe intensity (b). Thickness of the InGaAsP layers is 400 nm for all samples.

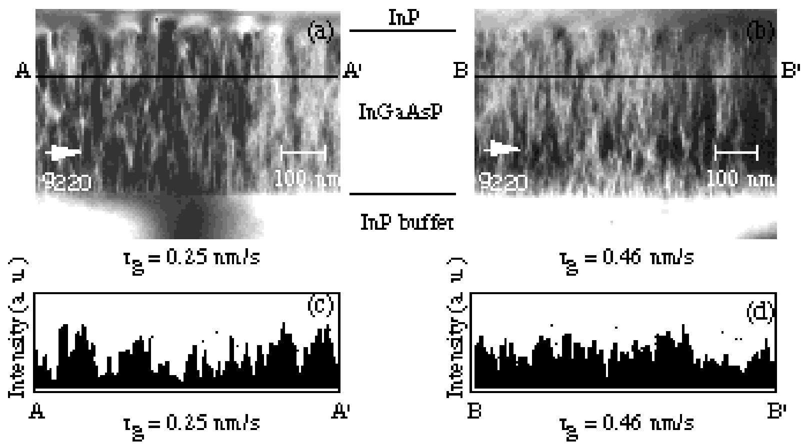

Fig. 2. (220) bright-field TEM micrographs of -0.37% tensile-strained InGaAsP layers grown at 0.25 nm/s (a) and 0.46 nm/s (b). Line profiles of contrast modulation along A-A' (c) and B-B' (d).

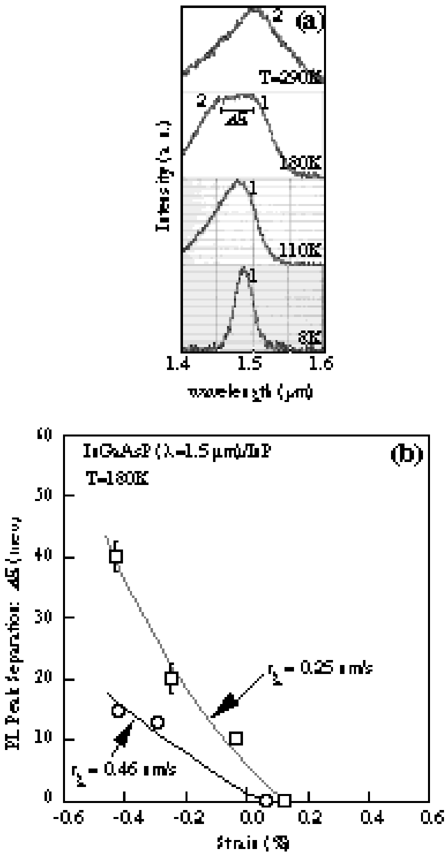

Fig. 3. Temperature dependence of PL spectra for -0.25% tensile-strained InGaAsP layer grown at 0.25 nm/s (a) and effect of strain and growth rate on peak separation ΔE measured at 180K (b).